REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Nov 2000	Proceedings of Environmental Ergonomics IX Jul 30-Aug

4. TITLE AND SUBTITLE
EFFICACY OF HEATED GLOVE LINERS

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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NATICK, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. ARMY MEDICAL RESEARCH & MATERIEL COMMAND
FORT DETRICK, MD 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Total handwear insulation (IT) is dependent on the rate of heat transfer in air through the skin-handwear interface, handwear layers, and the surface boundary air layer. Increasing air velocity reduces the insulation (Ia) provided by the boundary layer. As altitude increases, the corresponding decrease in air pressure and viscosity reduces convective heat loss. IT should therefore increase. The issue Light-duty glove (LD), Trigger-finger mitten (TF) and Arctic Mitten (AM), were tested as 2-layer systems at simulated altitudes of sea level, 2500 m and 5000 m in still air and at 5 m s-1 on a biophysical hand model. Overall, the effects of wind and altitude on IT were significant. Differences between 0 and 5000 m were significant, except for AM. Increases in IT greater than 10% are considered of sufficient magnitude to alter comfort sensation. Differences of that magnitude occurred most frequently between 0 and 5000 m, and least frequently between 2500 and 5000 m. The present results are consistent with an exponential drop in insulation with increasing altitude. Changes in IT were greater in still air and for less insulated handwear where the contribution of Ia to IT was more important.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Keywords: Cold, clothing, handwear, insulation, altitude	4
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
u	u	u	u

ENVIRONMENTAL ERGONOMICS IX

ICEE Ruhr 2000

The 9th International Conference on Environmental Ergonomics
Dortmund, Germany July 30 – August 4, 2000

Editors: Jürgen Werner & Martin Hexamer

Department of Biomedical Engineering, Medical Faculty
Ruhr-University Bochum, Bochum, Germany

Aachen 2000

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EFFICACY OF HEATED GLOVE LINERS

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INTRODUCTION

The thermal protection provided by clothing can be separated into three categories of descending importance: survival, function and comfort. Cold weather clothing items should provide sufficient protection for survival in the most extreme conditions expected. Individuals should also be able to function with minimal impairment during prolonged exposure within the normal range of thermal conditions and, under more moderate exposure, be well enough buffered from cold to be comfortable. During cold exposure, protection of the extremities is a critical concern in terms of survival, function and comfort [1]. The comfort threshold is a subjective factor dependent on environmental conditions, activity level, actual physiological conditions including skin and core temperature, and individual expectations. Enander [2] associated cold sensation with hand skin temperatures of 28 °C. She also indicated that pain occurred in the 20 to 21 °C range, but indicated others report the pain threshold in the 10 to 16 °C range. Over a series of handwear studies, our experience is that discomfort grades into pain below 10 °C. Functional criterion for hand temperatures are better defined. Performance of tasks that require manual dexterity begins to significantly deteriorate when finger surface temperatures fall below 15 °C, and most tactile sensitivity disappears when surface temperatures reach 4.5 °C [3,4]. Below 4.5 °C, loss of finger function becomes a long-term concern. A more immediate concern is protection from frostbite or other severe cold injury.

In cold environments, it is rarely possible to have handwear that will provide sufficient insulation to maintain functional hand temperatures indefinitely. In addition, heavily insulated handwear is often bulky and reduces both dexterity and tactile sensitivity. To perform tasks that require those capabilities, it is often necessary to remove handwear and work with only thin anti-contact gloves or bare hands. When there is a significant heat debt and only passive rewarming, it is not possible to rely on insulation to maintain functional hand temperatures. The alternative is auxiliary heating [5,6]. Several configurations of a Electrically Heated Handwear (EHH) system (Federal Fabrics-Fibers, Andover, MA), which has a heating element woven into the fabric, were investigated [7]. An early version of the EHH was described by McCormack and Webbon [8]. A U.S. Army Intermediate Cold/Wet Glove (ICWG) was the control [9]. The most viable approach was substitution of the heated liner from the EHH for the inner liner of the ICWG ensemble. The combination of the ICWG shell with a heated liner offers users an option of using the heated liner in place of the unheated liner as an anti-contact glove. Other reports have addressed the issue of dexterity with the prototype liner [8], but no comparison of dexterity between the prototype and an ICWG liner worn as an anti-contact glove is available.

METHODS AND MATERIALS

Extremity temperatures are, in large part, determined by the overall thermal state, but for a given clothing ensemble and activity level, endurance times (ET) are primarily a function of the thermal environment. Four subjects participated in this comparison. All subjects were tested first with the unheated liner, then the test was repeated the following day with the heated liner. Chamber conditions were -18 °C and 1.1 $m \cdot s^{-1}$ wind speed. All subjects participated in the study only after granting informed consent in accordance with AR 70-25 and USARIEM 70-25. The heated liner was derived from the EHH. The knitted liner is divided into heated areas and unheated areas. The

heating elements were knit into the thumb and finger areas. The remaining unheated areas are knit with synthetic yarn. The EHH glove liner has built-in electronic controls. Each digit has its own temperature measurement and control. An integrated circuit (IC) chip with an imbedded thermocouple monitors temperature and a second IC chip modulates the power delivered to the individual digit. The set-point temperature for power input during the tests was 22.5 °C. The EHH system is powered by a 6 Volt DC battery power supply (Procell PC918; Duracell, Bethel, CT). Clothing was the Extended Cold Weather Clothing System (ECWCS), which provided a total insulation value (I_T) of 3.6 clo. Subjects were seated for a maximum of 125 min (including 5 min set-up) with hands and forearms resting on a mesh platform at heart level to prevent both blood pooling or drainage in the lower arms and fingers. Rectal (T_{re}) and T_{sk} values were recorded every minute. Exposure limits were a T_{re} of 35.5 °C, or 5 °C for any surface temperature. Handwear I_T was measured with the biophysical hand model [10].

RESULTS

Given the emphasis on maintaining functional T_{sk} of 15 °C, the basis of subject removal was conservative, and subjects were removed after reporting persistent discomfort or pain. During the ICWG testing, no subject reached a T_{sk} of 5 °C. Final three-finger mean temperatures (T_f) (±SD) were 15.3±3.1 °C (heated) vs. 11.0±1.4 °C (unheated). ET values were 85±25 min (heated) vs. 46±16 min (unheated). Thus finger temperatures were maintained at functional temperatures for longer time periods relative to unheated conditions. Those results, plus two-finger averages for the right hand and right and left middle fingers, are reported in Table 1. The lowest observed T_{re} was 36.43 °C. There was a significant difference (p=0.022) between ET for heated vs. unheated ICWG,

TABLE 1. COMPARISON OF INTERMEDIATE COLD-WET GLOVES (ICWG) WITH HEATED OR UNHEATED LINERS

HANDWEAR	HEATED ICWG				UNHEATED ICWG			
VARIABLE	**ET MIN**	RIGHT °C	R/L °C	T_f °C	**ET MIN**	RIGHT °C	R/L °C	T_f °C
	120	12.36	14.29	13.43	66	7.29	11.50	9.59
	67	22.88	16.86	19.58	31	10.69	10.64	10.52
	86	17.99	15.25	15.31	35	8.01	13.98	11.15
	68	13.07	11.39	12.71	53	15.96	11.56	12.84
±SD	85 ±25	16.58 ±4.89	14.45 ±2.30	15.26 ±3.08	**46 ±16**	10.49 ±3.93	11.92 ±1.44	11.03 ±1.37

ET = ENDURANCE TIME (120 MIN MAXIMUM), **BOLD-FACE INDICATES DIFFERENCE IS SIGNIFICANT (P=0.022) FOR PAIRED-T TESTS.**
MEAN VALUES: T_f = (RMF+RLF+LMF)/3, RIGHT=(RLF+RMF)/2 R/L=(RMF+LMF)/2
WHERE RMF=RIGHT MIDDLE FINGER, RLF=RIGHT LITTLE FINGER, LMF= LEFT MIDDLE FINGER.

but not for any individual or combined finger temperatures. The lack of a statistical difference, despite longer ETs and a general observation that, in all cases, T_f was greater for the heated

condition, indicates that subjects exited at approximately the same T_f regardless of treatment. I_T values for ICWG with standard and prototype liners were both 1.1 clo.

DISCUSSION

When the option of supplemental or auxiliary heating is considered, there are several competing approaches. One strategy is to apply heat directly to the critical extremity. A second approach is to warm the central body mass. If sufficient heat is applied, vasoconstriction will be relaxed and heat carried by the blood will rewarm the extremities. The torso-heating strategy is analogous to local cold stress testing [2] during which the body is maintained at a comfortable room temperature while the extremity is exposed to more severe conditions. As subjects started from warm pre-test conditions, test results may be of limited application relative to actual field use in which individuals sleep in poorly heated shelters and are frequently moderately cold-stressed throughout the day.

Primary disadvantages of torso heating are the large power demand and the bulk of equipment required to meet that demand. A comparison of torso vs. hand heating is probably moot for a free-ranging, untethered individual, whereas both torso and hand heating are possible for an individual tethered to a continuous, unlimited power supply. Even the power supply for hand used during the study was, at present, too large and heavy for extended use. Brajovik et al. [11] presented data supporting the use of torso heating rather than extremity heating. They also raised the issue of insidious hypothermia. However, under the conditions of our study, with heating at a relatively low temperature (22.5 °C) for an exposure time of 120 min or less, our T_{re} measurements provided no indication of any unexpected decline, and T_{re} values remained well above even a conservative threshold for hypothermia.

An underlying concern with all auxiliary heating systems is dependence on the power supply. If the power supply is exhausted or malfunctions during routine use, tasks may simply be delayed until power can be restored or the system repaired. However, during emergencies such as the breakdown of public utilities or civil or military disturbances, critical tasks must be performed in extreme conditions. Complete reliance on any supplemental/auxiliary heat source under extreme conditions is hazardous. Even in vehicle or aircraft where the requisite power sources necessary to support torso or whole body heating is readily available, some residual insulating capability in auxiliary heated clothing is desirable in the event of equipment breakdown. The basic advantage of the ICWG with heated liner system is that the system retains the protection level of ICWG with an auxiliary heating capability. Another consideration is that heating systems are often evaluated as full-time heating systems, whereas they may also be employed as a supplemental or auxiliary system either for tasks requiring good manual dexterity or as a rewarming mechanism.

CONCLUSIONS

The substitution of the heat liner for the standard liner in the ICWG resulted in no measurable change in dry insulation. Thus the cold protection provided by the ICWG was retained. At -18 °C, heated liners delayed the decline in finger temperatures and extended ET, but power input was insufficient to prevent an eventual decline in finger temperature.

DISCLAIMER

The content and views presented in this report are those of the authors and should not be construed as an official Department of the Army position, view or policy. Citation of a product does not constitute endorsement.

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